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An investigation of quantification of image quality with respect to screen ruling on the appearance of multicolor print

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AN INVESTIGATION OF QUANTIFICATION OF IMAGE QUALITY WITH RESPECT TO SCREEN RULING ON THE APPEARANCE OF MULTICOLOR PRINT

by

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A thesis submitted in partial fulfillment
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M.S. DEGREE THESIS

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has been examined and approved
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ABSTRACT

Using a finer screen ruling will result in an improved final image quality in the color printing process. Studies have shown that beyond certain screen frequencies any further increase in the number of lines per inch has negligible benefit on multicolor process printing when using the half-tone printing precess. The objective of this research is to quantify the image quality of multicolor process printing by comparing the results of using several different screen rulings. The final image quality was subjectively evaluated based on the appearance of otherwise identical reproductions with the only difference being the screen ruling. The results of this research indicated that the relationship between the image quality and the screen rulings was not linear in the color printing process and the difference in image quality of reproductions made by using screen rulings of 133, 150, and 200 lines per inch was not significant.

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I. INTRODUCTION

The method of transforming a continuous tone copy into a printable image is to photograph the original through a half-tone screen. The screen ruling refers to the number of lines per inch measured along the screen angle. The vignette pattern on the screen breaks up the continuous tone of the original into an almost countless number of small dots. These dots are equally spaced. However, the size or diameter of the dots will vary according to the amount of light that was reflected from the different tones in the original. (Ref.1) When an image is printed using any printing system, the half-tone dots on the printing plate are used to transfer ink to the substrate to produce the reproduction. The ink printed by each dot has the same density. Large printing dots represent the shadow area of the reproduction, while the smaller dots represent the highlight area . What the human eye sees is the combination of the printed dot and the white paper surrounding it.

Contact screens are available from a coarse ruling of 65 line per inch to an extremely fine ruling of 500 line per inch. Theoretically the pattern of dots making up the final printed image will be less recognizable and less disturbing to the viewer's eyes by increasing the number of lines per inch of screen. In theory, a finer screen should result in a better final image. More detail will be shown and sharpness will be increased.

Good quality half-tone printing rarely uses coarse screen rulings comprising of 100 or less dots per inch. Newspaper printing may use 85 lines per inch or a coarser screen. By using a fine screen ruling between the range of 110 and 150 dots per inch will minimize the dot structure to the human eye making it less noticeable.

According to the report made by A.J.Herbert, the average screen ruling has increased from 120 line per inch in 1950 to 150 line per inch in 1982 and still keeps increasing in the lithographic printing.(Ref.2) Today, 150 line per inch is used very widely , with numerous specialists working with 175 line per inch and 200 line per inch or even finer screens. The screen ruling has increased very rapidly because of pressure from the advertisers for higher quality, and a few even use 300 lines screens, but very rarely use 500 lines per inch screen.

In general practice, the most widely used screen ruling is 150 line per inch for printing color on a coated stock using offset lithography. But, in fact, coarse screens are still used quite often. Some of the more commonly known reasons for the infrequent use of finer screens could be:(Ref.3) highlights and vignette are much more difficult to handle, tone reproduction is more difficult to control and correct and dot gain occurs more seriously.

The use of a very fine screen ruling is not impossible to print, however, it makes everything more critical in the process. Many variables need to be controlled in the printing process to have a good final image quality such as plate making, solid ink density and press--etc., but the finer screen exponents are not concerned with the problems related to use finer screen rulings. They use as fine a screen as possible, but time, equipment, and economics also create problems. Suppose we only consider the effect of screen ruling on the appearance of the final image, and if the problems of using a very fine screen could be eliminated, then what would be the screen ruling beyond which a further increase has negligible benefit? (Ref.4)

Neugebauer, Bickmure, and Rhodes studied the effects of screen ruling on the appearance of color prints.(Ref.5) They concluded that a 150 line per inch screen is good for the reproduction of originals with regular contours and good contrast. For small images and faces and other irregular details of low contrast can be achieved with a 200 line per inch screen. Screens finer than 200 line per inch show no improvement.

Many studies have been done on the problems and effects of screen ruling, but none has tried to quantify the image quality with respect to screen rulings. The objective of this research is to subjectively evaluate the image quality and then quantify it with respect to screen rulings. By using the method of paired comparison, the difference of image quality between each reproduction produced through various screen rulings were determined by the subjective evaluation of the judges. Once a number of judges categorizes all the sample prints, a relative linear subjective scale was obtained by using the method of least matrix and linear regression. Then the quantitative image quality of the reproductions with respect to screen ruling was determined.

II. OBJECTIVES

Studies have shown that using a finer screen ruling will result in an improved final image quality, but none has mentioned anything about the quantitative amount of improvement. Chantana Tangseree has researched the relationship between image quality and screen rulings in monochromatic half-tone images.(Ref.6) She concluded that output image quality is linear as a function of screen rulings. She also found that for a given reproduction system, there is a breaking point in the relationship, beyond that point, the improvement of image quality is not proportional to the increase of screen ruling with respect to the human visual perception.

The hypothesis of this research is that the image quality of half-tone multicolor prints is linear as a function of screen rulings and beyond a certain break point, the improvement of image quality is not proportional to the increase of screen ruling.

The objectives of this research are: (1) to subjectively evaluate the image quality of multicolor prints produced through 6 different screen rulings, (2) to quantify the image quality of those prints with respect to screen ruling, (3) to find the correlation between the image quality and the screen rulings, (4) to determine the breaking point of the improvement of the image quality.

III. LITERATURE REVIEW OF RELATED PROBLEMS

A. Dot Structure:

Through the printing process, the final images contain thousands of dots produced by screening. The shape of a dot can be square or diamond, with or without round corners, with or without curved sides, or nominally round, elliptical or pincushion in shape. An elliptical dot is sometimes referred to as a chain dot.

A study of dot shapes of contact screens has been made by R.E.Maurer.(Ref.7) He studied the effect of dot shape in image quality of reproduction and tried to find the best dot shape. He concluded that with chain dots, only two diagonal corners join at any one place in the tone scale, so the two small jumps occur that are normally imperceptible. Therefore, a chain dot screen was found to give the best overall result. By using a chain dot, vignette were produced more smoothly and without sudden change in hue and saturation. The experiment showed that a coarse screen ruling produces a sharper break than a fine screen ruling.

B. Resolving Power of The Human Eye:

The human eye is so constructed, physiologically and psychologically, that it can automatically translate a mass of fine, evenly spaced printed dots into an image that appears to be continuous tone to the human eye. Light and dark tonal values are determined by the percentage of space occupied by the surrounding white paper. The brain interprets the dots and white space and translates various sizes of dots into a continuous tone.(Ref.8) According to the research made by Herbert (Ref.9), for a 150 line per inch screen, a three percent dot is about 1.3 mils in diameter. If we viewed this area at a reasonable distance (one to two picture diagonals or more), our eyes can not resolve a three percent dot (between 5 and 10 mils is the limit, individual observers may vary.). The visual density difference between an area printed with three percent dots and a non printed area is just distinguishable under optimum circumstances. Using a 300 line per inch screen, a three percent dot would be about 0.6 mils across, and while this could be achieved by the best process under optimum conditions, it does not seem to be needed. Push the screen ruling to the maximum, is it really necessary ?

C. Dot Gain:

Dot gain refers to the measurable difference between a dot's original size on a half-tone separation film and its resulting finished size on a final reproduction. Two reproductions of the same image can be printed with the same identical solid ink density but visually differ dramatically from each other because of dot gain. It is now recognized as one of the most significant factors affecting printing quality and a major source of color variation.

According to the North American Print Survey reported by Muirhead, Burgstein, and Fahr,(Ref.10) dot gain varies proportionally with the screen ruling, decreasing as the ruling becomes coarser, with the largest amount of dot gain occurring near the mid-tone. A positive working print plate exhibits less dot gain than a negative working print plate. By using a 150 lines per inch elliptical screen, positive web printing has mid-tone gain of approximately 18 percent while negative web printing has mid-tone gain of approximately 24 percent.

There are two kinds of dot gain. One is referred to as mechanical dot gain. The parameters that may affect mechanical dot gain include: pressure between press cylinders, amount of exposure to the plate, type of blanket used, movement of press, --- etc. The choice of screen ruling has less influence on mechanical dot gain. The other one is referred to as optical dot gain.

Yule and Neilson has researched the causes of optical dot gain.(Ref.11) They found that some of the light which enters a half-tone pattern tries to come out through a dot, and is absorbed instead of being reflected. Light that we expect to be reflected is now absorbed. For a fifty percent dot, the absorption could be seventy five percent instead of fifty percent, thus increasing the density reading from 0.3 to 0.6. It happens most significantly at the mid-tone area because the mid-tone dots have larger surface areas than other dots have and hence gain the highest percentage of dot gain. This problem is referred to as Optical Dot Gain.

For a finer screen ruling, the distance between the printed dots decreases, therefore light has less distance to travel before it is absorbed by the printed dots. This gives some opportunities for light to strike a half-tone dot and being absorbed by that dots. Therefore by using a finer screen ruling there will be a greater percentage of optical dot gain.

D. Tonal Reproduction:

There are some parameters which affect the tonal reproduction in the printing process. The parameters include inking, pressure, screen ruling, and the plate packing. Those parameters will determine the final tone reproduction characteristics. An experiment has been made by Calabro, Fabbri and Laurenzi on the subject of what will influence the tonal reproduction in the printing process.(Ref.12) They reported that for a given paper and ink, the variables mostly influencing the tone rendering are screen ruling and inking; the remaining variables have less influence. They conclude that in order to determine the best printing conditions for a given pressure, ink and packing, it remains only to define the most suitable inking range and screen ruling.

E. Definition and Rendition:

L. E. Lausan has performed an experiment to find the rendition of photo-lithographic images produced through different screen rulings.(Ref.13) He defined definition as "the number of dots which forms the image of a one minimeter long line of the target" and the greater the resolution, the better the definition. He found that the detail rendition characteristics of regular half-tone images depend on the presence of unbroken dot arrays and also on the frequency and direction of the rows of the dots. The resolution and the definition (and hence the rendition) are directional. He concluded that in respect to regular half-tone images, the finer the screen ruling the better the rendition, and the less the dot range available to the printer. The dot range of the half-tone image decreases as the detail rendition increases.

Lauson also concluded that the finest screen capable of producing one percent dots composed of unbroken small highlight and opened shadow dots would be 250 lines per inch. A one percent array via 'finer' screen is extremely difficult to repeat and maintain through the printing production operations.

F. The Relationship Between Input and Output Image Quality

In a facsimile reproduction system, a linear relationship can be found in image quality between originals and reproduced images.(Ref.14) A straight line can be determined as a reference to indicate the quality of the reproduced images as figure 1 shows.

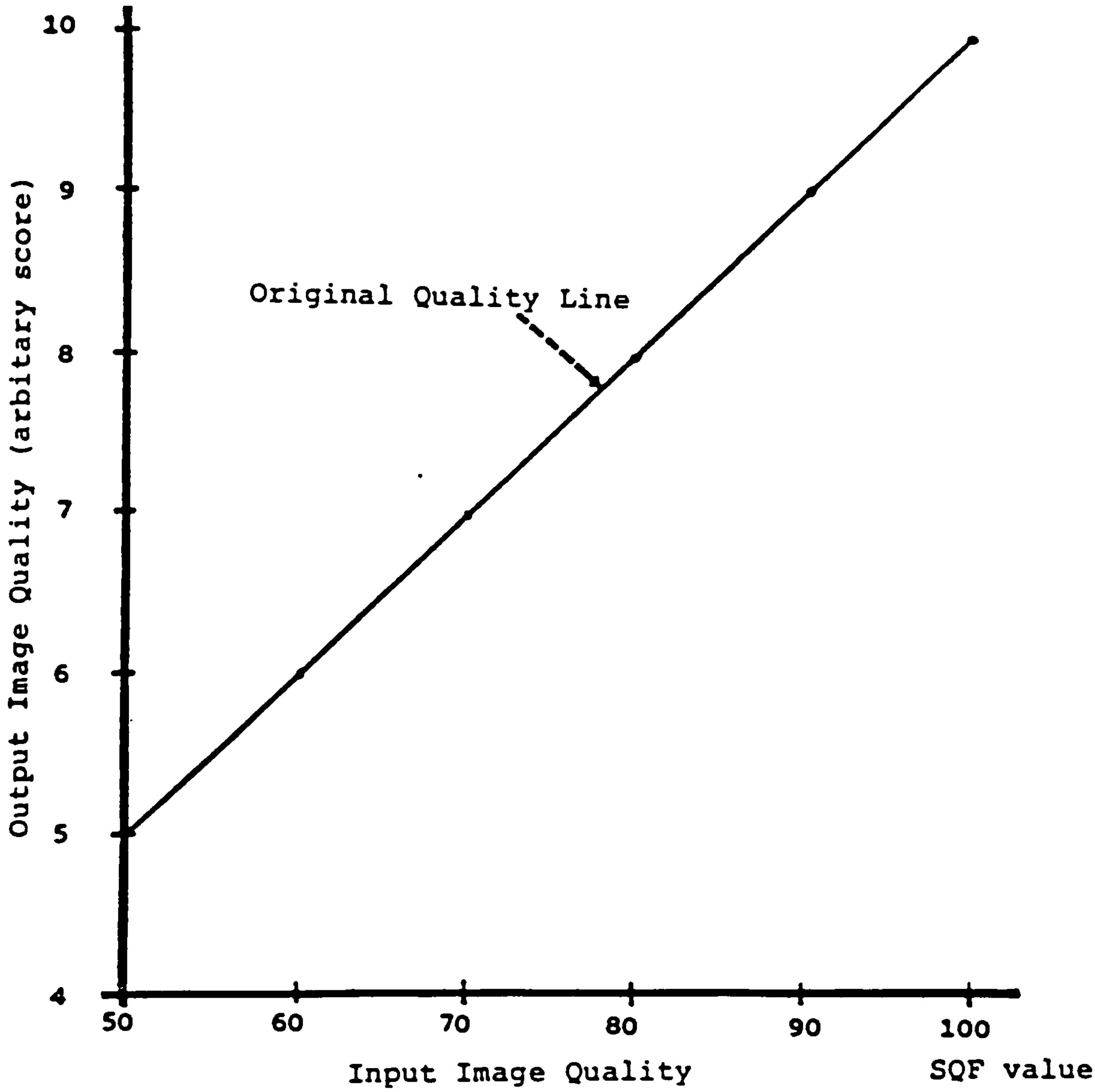

Figure 1: Image quality scaling model

(Courtesy of Granger)

When the originals are processed to have the reproduction in various quality levels ie. go through different screen rulings, we can expect the output image quality of these reproductions to form straight lines parallel to the originals's but are separated by different distances as shown in figure 2.

The distances between these straight lines may vary due to the variation in the printing process. They will not be evenly spaced. They will shift from one screen ruling to another when new variables are introduced into the existing reproduction system.(Ref.15) In order to identify the output difference of image quality and determine it quantitatively, the subjective quality factor was applied.

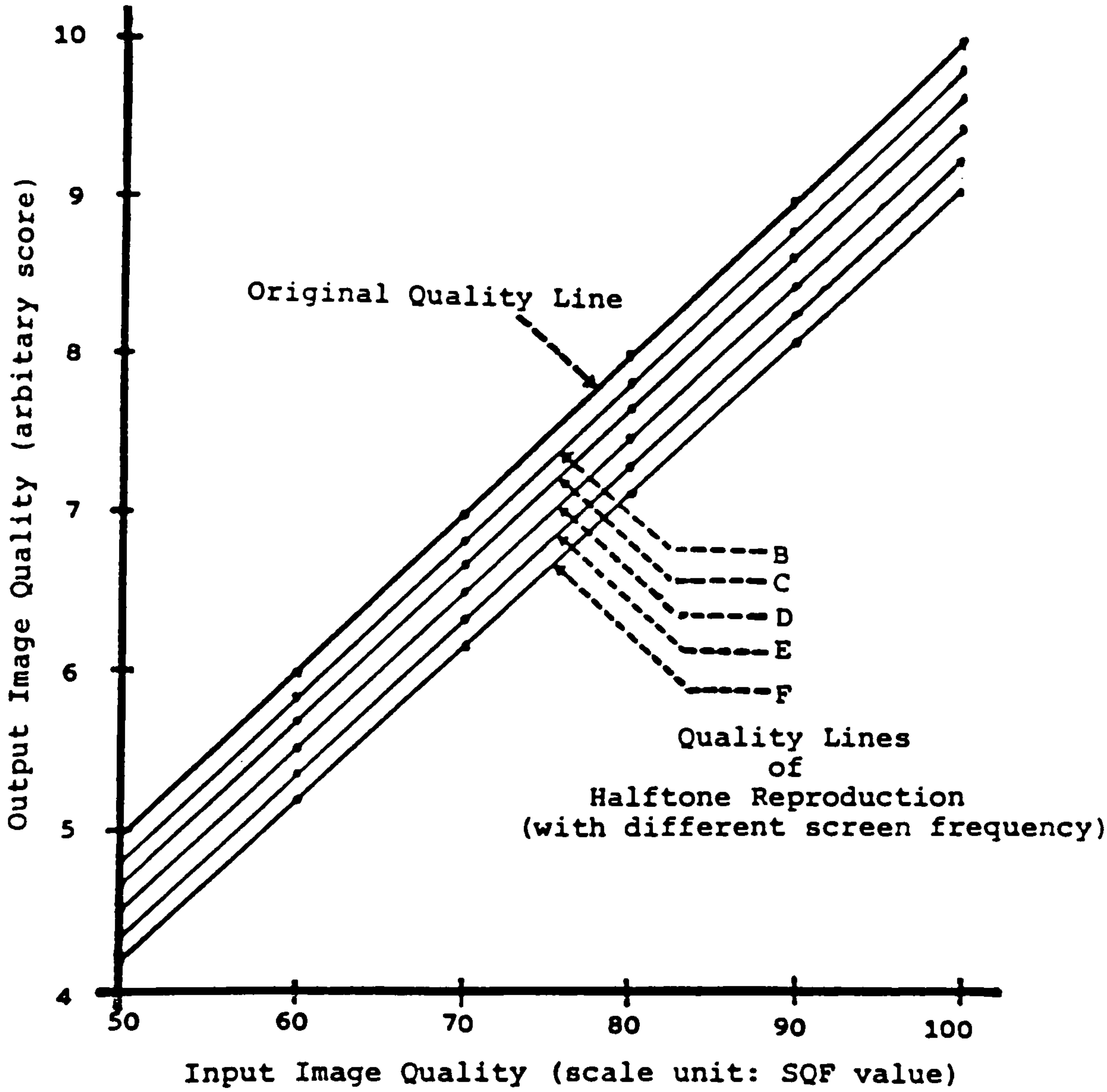

Figure 2: Image quality scaling model(halftone reproduction)

(Courtesy of Granger)

G. The Subjective Quality Factor (SQF):

The judgment of image quality is basically a psychological evaluation by the observer. Through the subjective evaluation procedure, it is very difficult to measure the image quality objectively and quantitatively. In order to measure the image quality quantitatively, the subjective quality factor (SQF) will be used.

The SQF was defined by Granger to describe the quality of an imaging system. (Ref.16) Granger limited the visual process by the image quality merit function (IQMF) by the subjective quality factor. SQF is a measure of image quality using the modulation transfer function (MTF) curve in the frequency region to which the eye is most sensitive. SQF was defined to duplicate the operation of the human visual system as shown in figure 3.(Ref.17) Where only a small band of Spatial frequencies is utilized at a normal viewing distance (approximately thirty four centimeters) This region of sharp visual response corresponds to a spatial frequency region of one half to two cycles per minimeter .

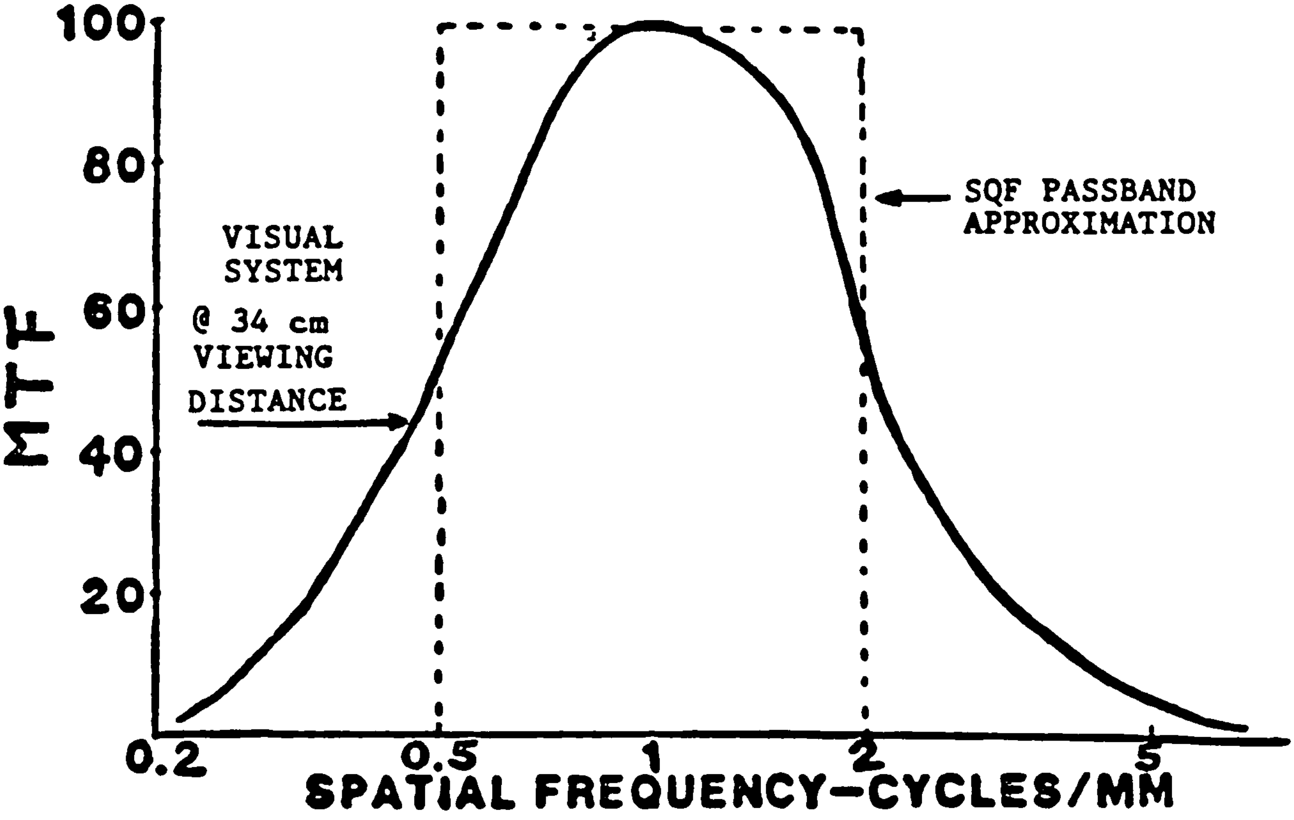

Figure 3: Subjective Quality Factor Bandpass

(Courtesy of Granger and Cupery)

SQF is calculated by the following equation:(Ref.18)

$$SQF = K \int_{M/2}^{2M} \int_{0}^{2} T(f,\theta)\, d\theta\, \frac{df}{f}$$

Where $T(f,\theta)$ is the optical transfer function in polar form, K is a scaling factor used to normalized the SQF factor and 1/f is the factor that imitates the integrative progress of the higher cortical cells of the brain. The variable M represents the bandpass nature of the early stage of the visual pathway.

Figure 4 was subtracted from Granger and Cupery.(Ref.19) The plot shows that the correlation of computed SQF value versus print quality rank received from subjective judgement is linear. The correlation between the predicted quality rank and the subjective assessment is 0.988. The degree of correlation indicates the model has accounted for all but two and one half percent of the variability in the subjective assessments. The details of the discussion reported by Granger and Cupery are as follows:

The points "0" were produced from images degraded by defocusing. Points "A" and "E" were tests of images asymmetry. Points "A" were from digital simulations and points "E" were a result of the off-axis imagery of a number of camera lenses. Points "G" and "S" were from analog simulations. Points "G" were representative of Gaussian OTFs and points "S" simulated centrally obstructed lenses. Points "K" and "T" were a test of film adjacency effects. The points " C" were analog simulations of contrast loss due to haze. In addition, the points " T" were a check on change in system magnification. The normal viewing distance of thirty four centimeter was used when viewing all points except those represented by points " T". Points "T" were observed at a five centimeters viewing distance with the aid of a magnifying glass. The same quality sample sets were used for both "K" and "T" assessments.

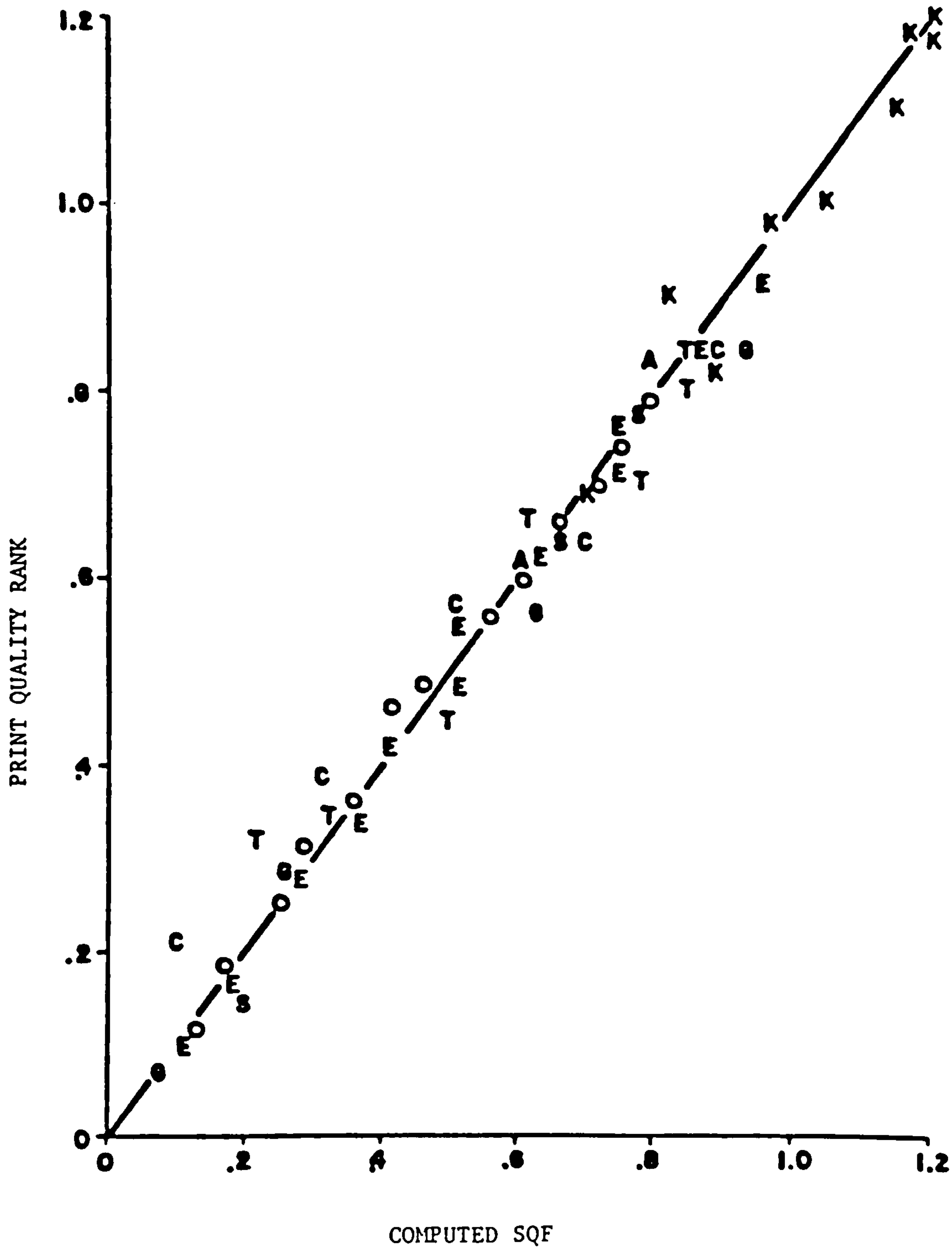

Figure 4: Subjective Rank versus SQF

(Courtesy of Granger and Cupery)

IV. METHODOLOGY

A. Sample Prints Preparation:

The originals which were used in this thesis work were: two continuous tone color transparencies and one continuous tone photographic print. The originals contained a low-key image, a normal-key image and a high-key image. The originals were scanned by the Hell DC-399ER electronic color scanner through six screen rulings which were 65, 85, 100, 133, 150 and 200 line per inch to produce the half-tone separations.

This experiment was only concerned with the relationship between the image quality and screen rulings; therefore, other parameters in the printing process that would affect the final print quality such as ink, paper, press, solid ink density,--etc. were all fixed. This was accomplished by using the 3M Matchprint Proofing System to produce the final prints. The 3M Matchprint Proofing system includes: 3M Matchprint Laminator, Olite Exposure System, Olix Light Integrator A1970, and MR427 Positive Proofing Processor. By using the 3M Matchprint SWOP/Group VI Positive Proofing Film, Exposed by using a light source which had the strongest output at 365 nonameters. The processing temperature was set at seventy five degree Fahrenheit. The optimum resolution of the reproductions was controlled by exposing all proofs to the same point on the 3M microline target as recommended by 3M for their Matchprint Color Proofing Material. The reproductions were expected to reproduce the dots in the range of at least two percent to ninety eight percent. The size of the final sample print was six and five eighth inch by five and one half inch.

B. Criterion of Subjective Evaluation:

Although image quality depends on a series of objective quantities, the quality of reproduced images are viewed and evaluated on the basis of subjective visual evaluation. In this experiment, the measurement of improvement or difference in image quality between prints using different screen rulings was derived by using the method of paired comparison.

Fifteen judges were used to subjectively evaluate the test prints. The judges for the testing were selected at random from the general public. A viewing booth with a standard 5000 degree Kelvin light source located at Sensi Complex of Center For Imaging Science of R.I.T. was used to provide a standard illumination for the subjective evaluation of the prints. The viewing distance was approximately thirty four centimeters. The judges were not allowed to touch the prints or permitted to change their ratings. Scratches, dirt spots, or any processing marks on the prints were to be ignored. The judges's satisfaction and preference was the basis of evaluation. The subjective evaluation was performed by using the method of paired comparison.

C. The Method of Paired Comparison:

Using the Paired Comparison method, fifteen judges were used to evaluate the prints. Images were selected in random order and shown to the judges in pairs. The judges were asked to compare one image to the other and indicate their preference. They were asked to be as consistent as possible.

Separations were made using six different screen rulings. The judges evaluated the images in pairs, therefore one original will result in fifteen combinations. Three originals will result in forty five combinations. Therefore, there were forty five pairs of reproductions to be evaluated by the judges.

The six test prints (produced from one original using six different screen rulings) were assigned arbitrarily to A, B, C, D, E and F. The objective was to find the relative ranking between the images in one set, A through F. The judges were asked to select one image over the other based on their personal preference. They were asked to indicate which print in the pairs do they consider to be better in the overall image quality and the distance between images. The relative distance of the image quality could be found by taking one image as the starting point and determining the distance of the other from this image. The rankings were given on a scale of one to ten. Ten points were given for the distance between the pair if a significant difference is observed. One point was given for the distance between the pair if a close image quality is observed. If there was no difference in image quality between the pair, then zero point was given for the distance. The scores were determined solely on the judge's personal preference. After the comparison of print A with others had been completed, print B was compared with the remaining prints and so on until all the comparisons were completed.

D. Data Manipulation:

For subjective comparisons, all measured value is based on the judge's personal preference; therefore, there is no absolute value for the measurement. All the measurement must be converted into a reference scale, then the relative distance (or value) of the comparison can be derived from this reference scale. In order to determine a reference scale, the method of the least square solution was applied. Therefore, an initiative matrix had to be set up to derive the least matrix as shown in figure 5.(Ref.20)

In this sample matrix, A was set to zero, the first row represented the distance from A to B (A-B). Since A was set to zero, A-B could be represented as -B or -1(B). At this point, only the distance from A to B was determined, and A was zero; therefore , A should not occupy any space in this matrix and the B column was set to -1. The remaining columns were set to 0. The second row represented the distance from A to C (A-C); therefore, C was set to -1 and the third row represented the distance from A to D (A-D); therefore, D was set to -1 and so on similarly for the rest of the rows and columns. There were fifteen combinations in each original and hence the matrix had fifteen rows.

B	C	D	E	F	
-1	0	0	0	0	A-B
0	-1	0	0	0	A-c
0	0	-1	0	0	A-D
0	0	0	-1	0	A-E
0	0	0	0	-1	A-F
1	-1	0	0	0	B-C
1	0	-1	0	0	B-D
1	0	0	-1	0	B-E
1	0	0	0	-1	B-F
0	1	-1	0	0	C-D
0	1	0	-1	0	C-E
0	1	0	0	-1	C-F
0	0	1	-1	0	D-E
0	0	1	0	-1	D-F
0	0	0	1	-1	E-F

Figure 5: The initiative matrix

The least square solution to this matrix was the least matrix:

Let

$$[\ LEAST\ ] = (\ [\ M\ ]^T \times [\ M\ ]\ )^{-1} \times [\ M\ ]^T$$

Where

$[\ M\ ]$ was the initial matrix

(a 15 x 5 matrix)

$[\ M\ ]^T$ was the transpose of the matrix $[\ M\ ]$

(a 5 x 15 matrix)

Note that

$[\ LEAST\ ]$ was a 5 x 15 matrix

$[\ M\ ]^T \times [\ M\ ]$ was a 5 x 5 matrix.

Let $[\ O.V.]$ = The vector of the observed values of distance obtained from evaluation

$[\ R.V.]$ = The vector of the final reference scale values

Again, note that

$[\ O.V.]$ was a 15 x 1 column vector

$[\ R.V.]$ was a 5 x 1 column vector

Now, we had

$$[\ M\ ] \times [\ R.V.] = [\ O.V.]$$

Multiplying both side on the left by $[\ M\ ]^T$ gave

$$[\ M\ ]^T \times [\ M\ ] \times [\ R.V.] = [\ M\ ]^T \times [\ O.V.]$$

Then, multiplying both side on the left by $([M]^T \times [M])^{-1}$

We had

$$([M]^T \times [M])^{-1} \times ([M]^T \times [M] \times [R.V.])$$

$$= ([M]^T \times [M])^{-1} \times [M]^T \times [O.V.]$$

Or $[R.V.] = ([M]^T \times [M])^{-1} \times [M]^T \times [O.V.]$

Since $([M]^T \times [M])^{-1} \times ([M]^T \times [M]) = I$

Therefore, we had

[Reference scale value] = [Least] * [observed value]

Where [LEAST] = $([M]^T \times [M])^{-1} \times [M]^T$

The equation showed that the multiplication of the least matrix with the observed value matrix will give us the relative distance (the reference scale values). The observed distance value could be either positive or negative simply decided by the direction of the judge's preference. The 5 x 15 matrix [Least] was multiplied by the 15 x 1 matrix [observed distance] and gave a 5 x 1 matrix indicating the relative distance (the reference scale values) of the image quality from each other. The 5 x 1 matrix was the representation of the relative distance of the group image determined by a particular judge. This matrix was referred as the individual reference value of that judge.

E. Regression:

In order to compare the individual reference value between judges, the judge's individual R.V. was converted into a common reference scale to form a group R.V.. The method of regression was used. Regression was used to provide a close approximation and the best possible fit to the data points. If the vertical Y was predicted by a+bx, then we should attempt to determine a and b so that the estimated errors were in some sense as small as possible and the sum of the square of the vertical deviation of the point from the line was a minimum.(Ref.21) In this research, the regression was performed by using the existing software package of Minitab in the VAX computer system.

Therefore, in order to form a common scale for all judges and then to find the best approximation of the subjective quality ranking, the regression of the average of the reference value on the individual reference value for each judge was performed. Then, the results calculated from the regression equations for each judge, each screen ruling, and each image respectively provided the final subjective image quality rankings. Those subjective image quality rankings would then have the same reference scale.

Since the originals were perfect photographic images, their image quality was rated at 100 on the SQF scale. The output image quality on the SQF scale were determined subjectively. Then, the relationship between the subjective image quality rankings and the output SQF values were obtained by the regression, thus, the subjective image quality rankings were converted into the SQF scale. When this was completed, the quantitative image quality was determined.

In order to find the best approximation of predicting image quality by the screen rulings, the regression of the quantitative image quality on the screen rulings was performed. Then the final quantitative image quality was determined by the regression equations.

V. RESULTS AND DISCUSSION

A. Experimental Results:

The subjective image quality rankings of the three images by the fifteen judges are shown in table one, two, and three. Those rankings have been manipulated to fit into the same scale.

The final subjective image quality rankings of each image obtained from the regression of the subjective image quality rankings on the screen rulings are shown in table four.

The data in table four was used to make the plots of the image quality rankings versus the screen ruling for three images respectively, and are shown in figure six.

The output quantitative image quality in SQF values obtained by transforming the image quality rankings into SQF values for each image and each screen ruling are shown in table five.

The final quantitative image quality of the reproductions made through various screen rulings are shown in table six.

The data in table 6 was used to make the plots of the final quantitative image quality versus the screen rulings and shown in figure seven, eight, and nine.

NORMAL-KEY IMAGE

JUDGE	65	85	100	133	150	200
1	-5.96	-2.58	-0.06	1.86	2.84	2.81
2	-5.23	-1.50	-1.28	3.40	4.49	4.46
3	-2.23	-1.04	-0.15	0.53	0.88	0.87
4	-4.87	-2.42	-0.59	0.80	1.51	1.50
5	-6.45	-2.88	-0.22	1.81	2.84	2.82
6	-5.00	-1.60	0.94	2.87	3.86	3.84
7	-5.07	-2.21	-0.08	1.55	2.38	2.36
8	-7.03	-4.01	-1.76	0.00	0.84	0.82
9	-3.94	-1.92	-0.42	0.73	1.31	1.29
10	-4.73	-1.68	0.59	2.33	3.21	3.19
11	-2.81	-0.89	0.54	1.64	2.19	2.18
12	-2.31	-1.16	-0.30	0.36	0.69	0.69
13	-4.29	-0.23	2.79	5.10	6.28	6.25
14	-5.21	-3.30	-1.89	-0.81	-0.25	-0.27
15	-6.92	-3.58	-1.08	0.83	1.80	1.78

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

Table 1: The image quality rankings of the normal-key image

HIGH-KEY IMAGE

JUDGE	65	85	100	133	150	200
1	-4.31	-1.95	0.33	2.73	2.74	2.47
2	-6.01	-2.94	0.02	3.12	3.13	2.79
3	-2.63	-0.94	0.68	2.39	2.40	2.21
4	-4.22	-1.57	0.98	3.66	3.67	3.38
5	-5.54	-2.90	-0.35	2.33	2.34	2.05
6	-5.49	-2.02	1.32	4.83	4.84	4.46
7	-4.63	-1.92	0.62	3.32	3.33	3.03
8	-7.08	-4.16	-1.33	1.63	1.65	1.32
9	-3.29	-1.88	-0.52	0.91	0.92	0.76
10	-4.32	-2.21	-0.17	1.97	1.98	1.75
11	-4.20	-2.58	-1.02	0.62	0.62	0.45
12	-0.99	-0.28	1.50	2.78	2.79	2.65
13	-3.90	-1.06	1.67	4.54	4.55	4.24
14	-4.19	-2.06	0.00	2.16	2.17	1.93
15	-7.43	-5.35	-3.35	-1.25	-1.24	-1.47

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

Table 2: The image quality rankings of the high-key image

LOW-KEY IMAGE

JUDGE	65	85	100	133	150	200
1	-4.65	-1.27	0.19	3.10	3.76	4.41
2	-5.22	-2.21	-0.79	2.04	2.69	3.32
3	-1.85	-0.16	0.64	2.23	3.59	2.95
4	-2.32	-0.21	0.78	2.76	3.22	3.65
5	-4.48	-0.65	1.16	4.76	5.58	6.38
6	-5.74	-1.66	0.26	4.09	4.97	5.82
7	-5.32	-2.25	-0.80	2.08	2.74	3.37
8	-5.13	-2.17	-0.78	1.99	2.63	3.25
9	-2.16	-0.95	-0.38	0.75	1.01	1.26
10	-3.38	-1.14	0.08	2.02	2.50	2.96
11	-2.94	-0.75	0.28	2.33	2.80	3.26
12	-2.38	-1.20	-0.64	0.47	0.72	0.97
13	-5.28	-1.55	0.20	3.67	4.46	5.23
14	-4.62	-1.77	-0.43	2.24	2.86	3.45
15	-5.36	-1.69	0.03	3.48	4.27	5.04

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

Table 3: The image quality rankings of the low-key image

SCREEN RULING	65	85	100	133	150	200
NORMAL-KEY IMAGE	-4.77	-2.07	-0.52	1.71	2.30	2.16
RANKING	6	5	4	3	1	2
HIGH-KEY IMAGE	-4.70	-1.81	-0.17	2.11	2.66	2.15
RANKING	6	5	4	3	1	2
LOW-KEY IMAGE	-4.04	-1.43	0.09	2.44	3.16	3.65
RANKING	6	5	4	3	2	1

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

Table 4: The final subjective image quality rankings

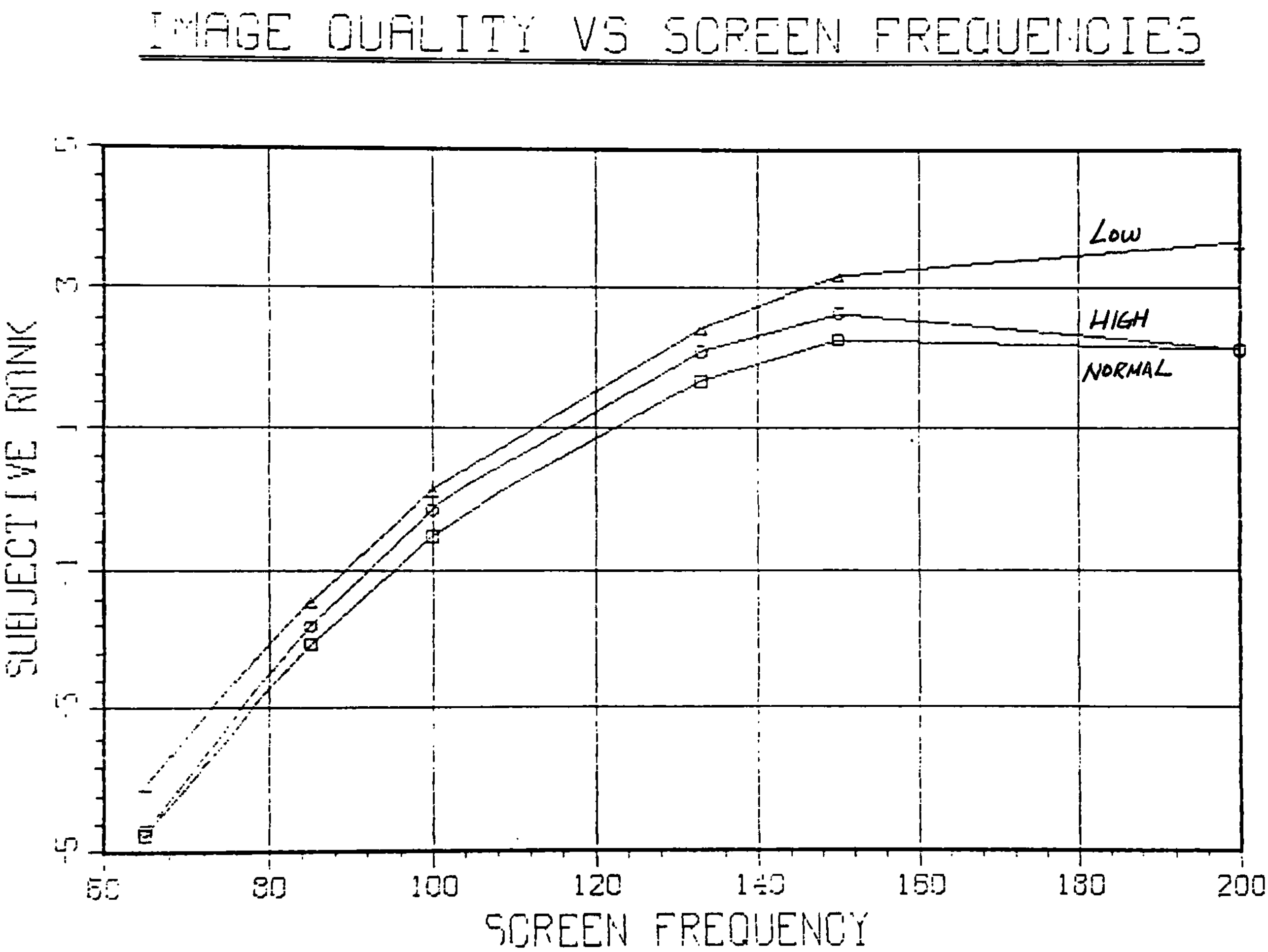

Figure 6: The final subjective image quality rankings versus the screen rulings

SCREEN RULING	65	85	100	133	150	200
NORMAL-KEY IMAGE	81.94	85.96	90.04	93.16	94.74	94.72
HIGH-KEY IMAGE	79.97	85.52	90.87	96.46	96.49	95.87
LOW-KEY IMAGE	78.97	85.07	87.98	93.67	94.83	96.27

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

*The output image quality values are on SQF scale, a perfect photographic image is rated 100 on SQF scale.

Table 5: The output quantitative image quality in SQF values of three images

SCREEN RULING	65	85	100	133	150	200
NORMAL-KEY IMAGE	82	87	89	94	95	95
HIGH-KEY IMAGE	80	86	90	96	97	96
LOW-KEY IMAGE	80	85	88	93	95	96

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

*The image quality values are on SQF scale, a perfect photographic image is rated 100 on SQF scale.

Table 6: The final quantitative image quality of the three images

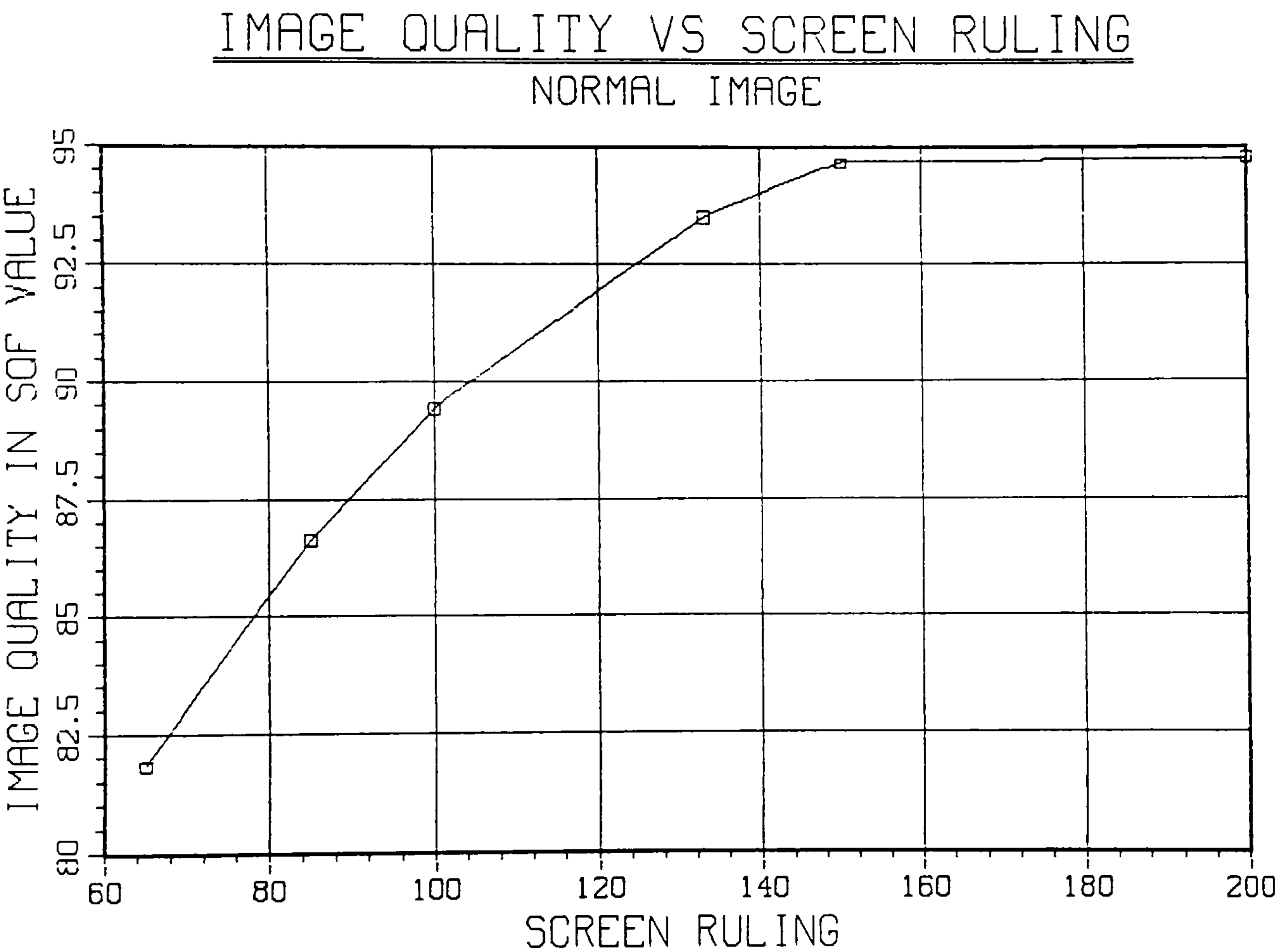

Figure 7: The final quantitative image quality of the normal image versus the screen rulings

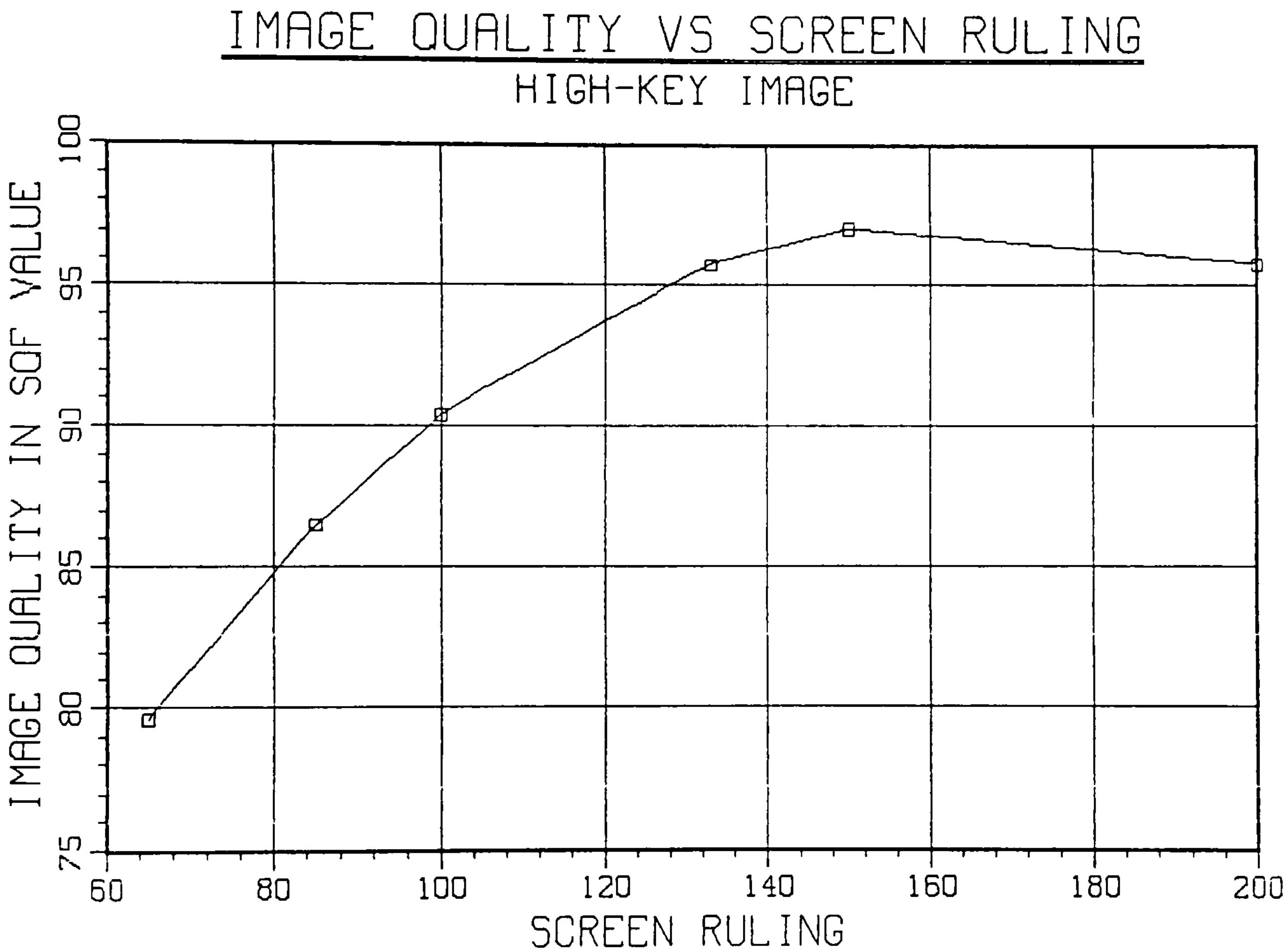

Figure 8: The final quantitative image quality of the high-key image versus the screen rulings

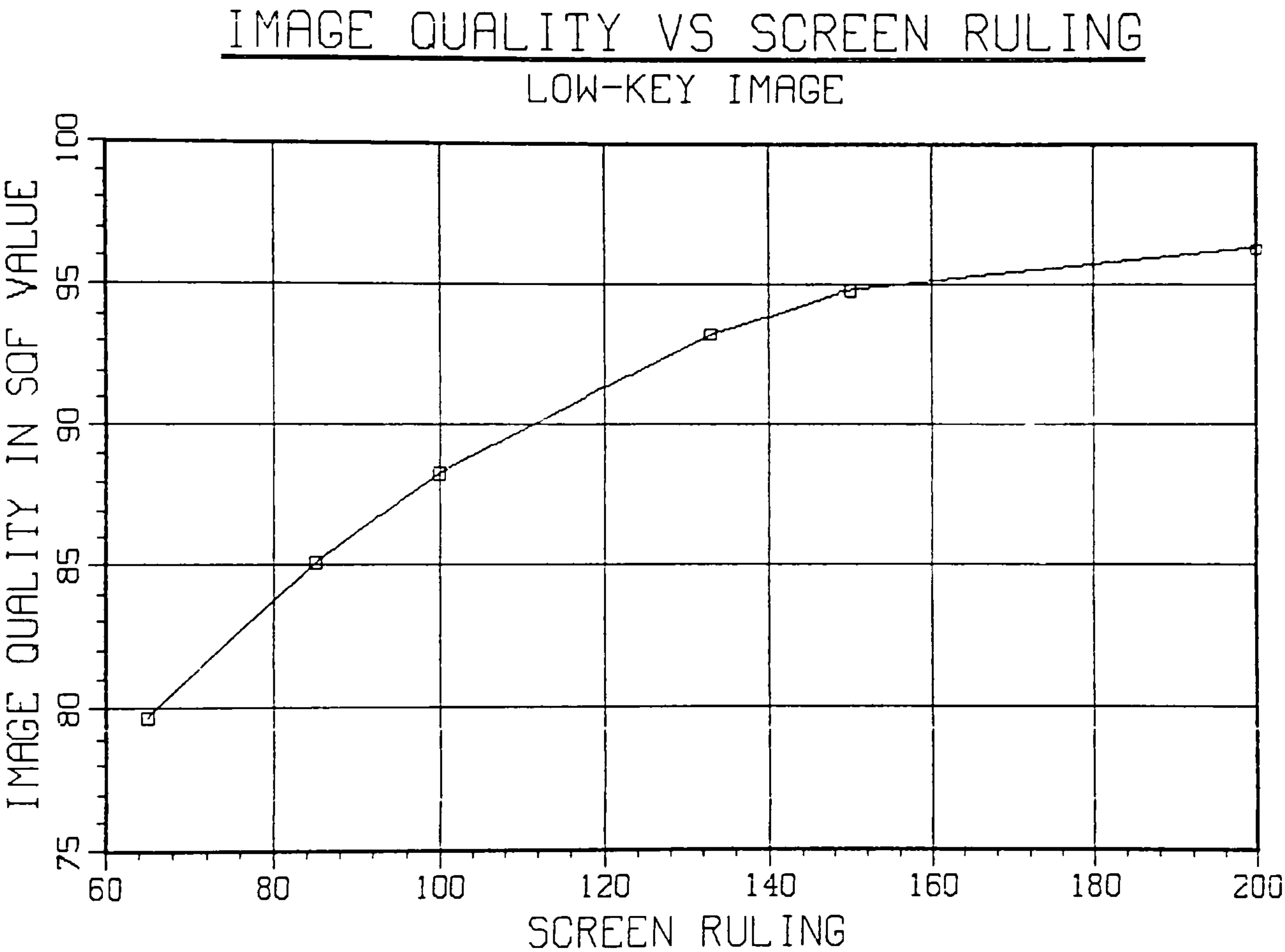

Figure 9: The final quantitative image quality of the low-key image versus the screen rulings

B. Discussion:

Since tone reproduction has a marked effect on the subjective judgment of image quality, during the preparation of color separations, considerable effort was expended to obtain the same tone reproduction and color rendition with all tested screen rulings. The optimum resolution of the reproductions was controlled by exposing all proofs to the same point on the 3M microline target as recommended by 3M for their 3M Matchprint Color Proofing Material. Therefore, the different between reproductions will be only the screen rulings.

The final regression equations obtained from the experiment for the normal-key image was $Y=38.0+5.76\sqrt{X}-0.000617X^2$, for the high-key image was $Y=15.2+8.51\sqrt{X}-0.000994X^2$, and for the low-key image was $Y=32.1+6.21\sqrt{X}-0.000592X^2$. Therefore, the results of the research indicate that the relationship between the tested reproductions and the tested screen rulings in the multicolor printing process is not linear. As shown in figure seven, eight, and nine, the patterns of the relationship are represented by concave curves, however, the resulting plots do show that the relationship is approximately linear within the range of the screen ruling between 65 and 150 lines per inch. It will be discussed respectively for the three images in the following sections.

1. Normal-key image

The results of this research as shown in table six indicated that the values of the image quality of the reproduction of the normal-key image increased from 82 to 95 SQF values as the frequencies of screen ruling increased from 65 to 150 lines per inch, but remained at 95 SQF values as the frequencies of screen ruling moved up to 200 lines per inch. As shown in figure seven, the relationship between the image quality of the reproductions and the screen ruling is approximately linear if the screen ruling is within the range of 65 and 150 lines per inch. Between the screen ruling of 150 and 200 lines per inch, the change of image quality of the reproduction is very slight and not noticeable.

The maximum values of the image quality calculated from the regression equation is 95 SQF values at the screen ruling of 176 lines per inch. The values of the image quality start to decline beyond that point. Since the results of the experiment have already given 95 SQF values at the screen ruling of 150 lines per inch, the breaking point of the image quality of the reproduction of the normal-key image is the screen ruling of 150 lines per inch.

2. High-key image:

The results of this research as shown in table six indicated that the values of the image quality of the reproduction of the high-key image increased from 80 to 97 SQF values as the frequencies of the screen ruling increased from 65 to 150 lines per inch. It declined to 96 SQF values as the frequencies of the screen ruling moved up to 200 lines per inch. The relationship between the image quality of the reproductions and the screen rulings is approximately linear if the screen ruling is within the range of 65 and 150 lines per inch as shown in figure eight. The results of this research also indicated that the reproduction produced by a screen ruling finer than 150 line per inch shows no improvement in image quality.

The maximum values of image quality of the reproduction calculated from the regression equation is 97.5 SQF values at the screen ruling of 166 lines per inch. The values of the image quality start to decline beyond that point. Therefore, the breaking point of the image quality of the reproduction of the the high-key image is the screen ruling of 166 lines per inch.

3. Low-key image:

The results of this research as shown in table six indicated that the values of the image quality of the reproduction of the low-key image increased from 80 to 96 SQF values as the frequencies of the screen ruling increased from 65 to 200 lines per inch. Although the trend is that the values of the image quality of the reproduction increases as the frequencies of the screen ruling increase, since the regression equation obtained from the experiment was $Y=32.1+6.21\sqrt{X}-0.000592\ X^2$, the relationship between the image quality of the reproductions and screen rulings is still not linear. But within the range of 65 and 150 lines per inch, the relationship is approximately linear as shown in figure nine.

In the case of the low-key image, the sample image consisted of a nature scene which carried a lot of detail and small objects. The data of the research indicates that the reproduction made by using a screen ruling of 200 lines per inch has better image quality than those made by a coarser screen ruling in the case of the low-key image. The judges seemed to prefer the image reproduced by using a screen ruling of 200 line per inch. The improvement in image quality is one SQF values between the reproductions made by using the screen ruling of 150 and 200 lines per inch. In general, the just noticeable difference of image quality in SQF values is three, therefore, the difference in image quality is not really significant between the reproductions made by using the screen ruling of 150 and 200 lines per inch in the case of low-key image.

The maximum values of the image quality of the reproduction calculated from the regression equation is 96 SQF values at the screen ruling of 190 lines per inch. The values of the image quality of the reproduction start to decline beyond that point, therefore, the breaking point of the image quality of the reproduction of the low-key image is the screen ruling of 190 lines per inch.

In the case of the normal-key image, the reproductions made by using the screen rulings of 150 and 200 lines per inch had the same values of image quality which was 95 SQF values. The judges could not tell the difference between these two images. In the case of the high-key image, the difference in the values of the image quality of the reproductions made by using 150 and 200 lines per inch was one SQF values. The judges seemed to prefer the image quality of the reproduction made by using the screen ruling of 150 lines per inch rather than the one made by using the screen ruling of 200 lines per inch. The reason for this preference is not known. Since the normal-key consisted of a glass cup and a hand, and the high-key image consisted of a cigarette box, a bracelet, and a pearl necklace, those objects carried regular outlines. There may be two explanations. The first was offered by Neugebauer, Bickmore, and Rhodes. They have shown that physiologists have proven that when there is sufficient information in the image to tell the observer's eye (or brain) that there is a regular line or shape that he is familiar with, the eye will complete the missing information instinctively so that the observer does not become consciously aware of how irregular the line really is on the image.(Ref.22) The second reason may be that the viewing distance was set at thirty four centimeters, making the difference between the image quality produced by using a screen ruling of 150 and 200 lines per inch just beyond the resolving power of the human eye. In either case, according to the data of this research, using a screen ruling finer than 150 liner per inch does not result in an improved image quality of the reproductions of the normal-key and high-key images.

The resulting equations of regression of quantitative image quality on the screen rulings are shown in table seven. It also shows the values of r-square.

IMAGE	REGRESSION EQUATION	r-SQUARE
NORMAL KEY	$Y = 38.0 + 5.76\sqrt{X} - 0.000617\ X^2$	99.3%
HIGH KEY	$Y = 15.2 + 8.51\sqrt{X} - 0.000994\ X^2$	99.1%
LOW KEY	$Y = 32.1 + 6.21\sqrt{X} - 0.000592\ X^2$	99.9%

Table 7: The resulting equations of regression of the quantitative image quality on the screen rulings

To measure the fitness of the regression equation for the data, the square of the Pearson Product-Moment Correlation Coefficient (r-square) is used to interpret the relationship of the two variables. The two variables in this research are the quantitative image quality and the screen rulings. R-square measures the percentage variation in the data explained by the regression equation. When r-square is equal to one, the regression explains one hundred percent of the total variation, when r-square is equal to zero, the regression is independent from the data. As indicated by the results of this research, the r-square is very close to one, therefore, a highly degree of linear association between the quantitative image quality and screen rulings is indicated.

Since the experiment is based solely on the judges's subjective preference, it is possible that some factors might affect the judges's judgment. Mistakes might be made by any judge during the period of evaluation, if the judge were disturbed or affected by the surrounding circumstance or the nature of the images. The results of the experiment indicated that this influence is less than one percent, only less than one percent of the data could not be interpreted by the regression equations.

VI. CONCLUSIONS:

Theoretically, using a finer screen ruling will result in an improved color image quality in the multicolor printing process. Based on the data of this research, this statement holds true for the reproductions of the low-key image from the screen ruling of 65 to 200 lines per inch, for reproduction of the normal-key image and high-key image from 65 to 150 lines per inch. The difference in the quantitative image quality between the reproductions made by using the screen rulings of 133, 150, and 200 lines per inch for the three images were less than two SQF values. The only exception was the difference in quantitative image quality of reproductions made by 133 and 200 lines per inch of the low-key image which was three SQF values. In general, the just noticeable difference of image quality in SQF values are three, therefore, as indicated by the results of this research, the difference in image quality of the reproductions made by using the screen rulings of 133, 150, and 200 lines per inch is not significant.

Tangseree has reported that output image quality is linear as a function of screen ruling in the monochromatic printing process. The results of this research indicate that the relationship between the image quality of the reproductions and the screen rulings is not linear in the multicolor printing process. Between the range of 65 and 150 lines per inch, the image quality of the reproduction did increase as the frequencies of the screen ruling increased. The relationship is approximately linear between the image quality of the reproductions and the frequencies of the screen rulings if the screen ruling is within this range. Between the screen ruling of 150 and 200 lines per inch, the image quality of the reproduction remained the same for the normal-key image, decreased one SQF values for the high-key image, and increased one SQF values for the low-key image.

The results of this research also indicated that there is a breaking point of the improvement of the output image quality, and the values of image quality start to decline if the frequencies of the screen ruling move up beyond this point. As indicated by the regression equations, the breaking point of this improvement for the normal-key image is the screen ruling of 150 lines per inch, the breaking point of this improvement for the high-key image is the screen ruling of 166 lines per inch, and the breaking point of this improvement for the low-key image is the screen ruling of 190 lines per inch.

VII. SUGGESTION FOR FUTURE WORK

The type of ink and paper used in the color printing process has a very remarkable effect on the final image quality of a reproduction. Dot gain could be the most serious problem. The advantage of using the 3M Matchprint proofing system is that all the other parameters in the printing process that will affect the final image quality of the reproduction are all controlled. Therefore, the effect of the screen ruling can be studied without being affected by other parameters to simplify the problem. The results of this research have offered some very valuable information and conclusions related to the relationship between the image quality of color reproductions and screen rulings, however, there are still some problems that this research did not cover. Future research should concentrate on the subject matter, using different images, repeating the experiment and actually print the images on a printing press, finding out the relationship between the image quality of the reproduction, the subjects, and screen rulings, and investigating the impact of ink, paper, and press on the final image quality of reproductions made by various screen rulings.

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IX.APPENDIX

Appendix 1

The least matrix

-1/3	-1/6	-1/6	-1/6	-1/6	1/6	1/6	1/6	1/6	0	0	0	0	0	0
-1/6	-1/3	-1/6	-1/6	-1/6	-1/6	0	0	0	1/6	1/6	1/6	0	0	0
-1/6	-1/6	-1/3	-1/6	-1/6	0	-1/6	0	0	-1/6	0	0	1/6	1/6	0
-1/6	-1/6	-1/6	-1/3	-1/6	0	0	-1/6	0	0	-1/6	0	-1/6	0	1/6
-1/6	-1/6	-1/6	-1/6	-1/3	0	0	0	-1/6	0	0	-1/6	0	-1/6	-1/6

Appendix 2

The original reference values of the normal image

NORMAL-KEY IMAGE

JUDGE	65	85	100	133	150	200
1	-5.83	-2.67	0	2.00	2.67	3.83
2	-4.67	-1.83	0	5.00	3.67	4.83
3	-2.75	-0.25	0	1.58	1.08	-0.67
4	-4.17	-3.50	0	-0.50	1.50	2.67
5	-7.67	-0.83	0	1.67	2.33	2.50
6	-6.00	0.83	0	2.17	4.83	3.17
7	-4.83	-2.33	0	0.00	2.83	3.33
8	-6.83	-5.00	0	-1.00	1.33	0.50
9	-3.83	-2.67	0	0.17	1.17	1.67
10	-4.17	-2.00	0	2.00	3.00	4.17
11	-2.17	-1.67	0	2.83	2.00	2.00
12	-1.83	-2.00	0	-0.17	1.33	0.67
13	-3.00	-0.83	0	5.67	6.33	7.83
14	-6.25	-2.58	0	0.00	-0.75	-1.92
15	-7.17	-3.67	0	1.83	1.83	0.17

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

Appendix 3

The original reference values of the high-key image

HIGH-KEY IMAGE

JUDGE	65	85	100	133	150	200
1	-4.50	-1.50	0	3.67	3.00	1.33
2	-5.83	-3.33	0	3.17	2.83	3.17
3	-3.00	-0.08	0	2.50	3.50	1.08
4	-3.83	-1.67	0	3.83	4.83	2.83
5	-6.67	-1.50	0	0.83	1.00	4.33
6	-4.67	-2.67	0	3.83	5.17	6.33
7	-4.83	-2.67	0	4.00	2.83	1.67
8	-7.17	-4.83	0	0.83	1.17	2.00
9	-3.25	-2.17	0	-0.50	1.42	1.50
10	-4.67	-1.83	0	1.67	1.33	2.50
11	-3.50	-4.17	0	-0.17	0.83	1.00
12	-1.00	1.00	0	3.00	2.67	3.33
13	-2.83	-1.83	0	6.33	6.00	2.33
14	-4.00	-2.50	0	1.50	1.17	3.83
15	-9.17	-4.17	0	0.83	-2.00	-5.50

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

Appendix 4

The original reference values of the low-key image

LOW-KEY IMAGE

JUDGE	65	85	100	133	150	200
1	-4.08	-1.50	0	3.25	3.83	4.50
2	-6.17	-0.83	0	0.00	3.00	4.00
3	-1.75	0.00	0	3.33	2.75	2.17
4	-2.50	0.50	0	3.83	2.67	3.50
5	-4.17	-0.33	0	5.33	5.67	6.50
6	-5.83	-1.33	0	3.33	6.33	5.50
7	-4.67	-3.67	0	1.67	3.17	3.50
8	-5.67	-1.83	0	2.00	2.17	3.33
9	-2.33	-1.00	0	0.42	1.67	0.75
10	-2.83	-2.17	0	2.67	2.33	3.00
11	-3.00	-0.33	0	1.67	3.00	3.67
12	-2.50	-1.50	0	0.83	0.17	1.00
13	-5.00	-1.67	0	3.50	4.50	5.67
14	-4.88	-1.83	0	3.50	1.83	3.33
15	-5.17	-1.83	0	3.17	4.33	5.50

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

Appendix 5

The average of the image quality rankings of three images

SCREEN RULING	65	85	100	133	150	200
NORMAL-KEY IMAGE	-4.08	-2.07	-0.03	1.53	2.32	2.31
HIGH-KEY IMAGE	-4.55	-2.22	0.03	2.38	2.39	2.13
LOW-KEY IMAGE	-4.03	-1.31	-0.01	2.53	3.05	3.69

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

Appendix 6

The average of the original output image quality

SCREEN RULING	65	85	100	133	150	200
NORMAL-KEY IMAGE	81.67	86.67	88.33	95.00	95.00	93.33
HIGH-KEY IMAGE	80.00	85.00	91.67	95.00	98.33	95.00
LOW-KEY IMAGE	80.00	85.00	86.67	90.00	96.67	98.33

*The unit of 65, 85, 100, 133, 150, and 200 is line per inch

*The output image quality values are in SQF values

Appendix 7

The resulting equations and r-square values of regression of the output image quality on the image quality rankings

IMAGE	REGRESSION EQUATION	r-SQUARE
NORMAL-KEY	$Y = 90.1 + 2.00\ X$	94%
HIGH-KEY	$Y = 90.8 + 2.38\ X$	96%
LOW-KEY	$Y = 88.0 + 2.24\ X$	88%

Appendix 8

IMAGE QUALITY EVALUATION SHEET

1) Make a check mark to indicate which image you consider is better.

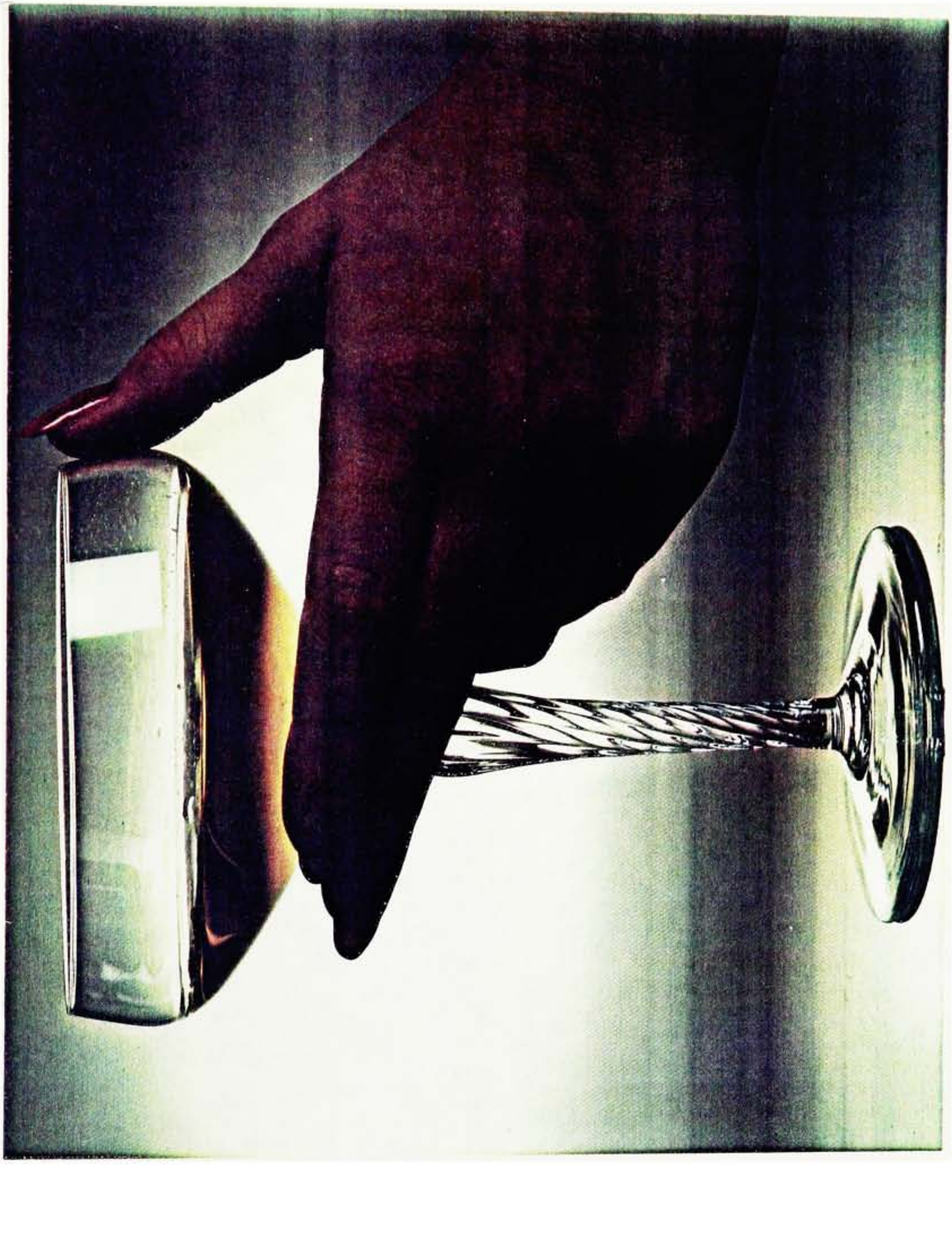
2) Give a score on a scale from 1 to 10 to indicate the quality difference. 0 means no difference. 10 means very different.

IMAGE 1	IMAGE 2	IMAGE 3
__A - B__ ( )	__A - B__ ( )	__A - B__ ( )
__A - C__ ( )	__A - C__ ( )	__A - C__ ( )
__A - D__ ( )	__A - D__ ( )	__A - D__ ( )
__A - E__ ( )	__A - E__ ( )	__A - E__ ( )
__A - F__ ( )	__A - F__ ( )	__A - F__ ( )
__B - C__ ( )	__B - C__ ( )	__B - C__ ( )
__B - D__ ( )	__B - D__ ( )	__B - D__ ( )
__B - E__ ( )	__B - E__ ( )	__B - E__ ( )
__B - F__ ( )	__B - F__ ( )	__B - F__ ( )
__C - D__ ( )	__C - D__ ( )	__C - D__ ( )
__C - E__ ( )	__C - E__ ( )	__C - E__ ( )
__C - F__ ( )	__C - F__ ( )	__C - F__ ( )
__D - E__ ( )	__D - E__ ( )	__D - E__ ( )
__D - F__ ( )	__D - F__ ( )	__D - F__ ( )
__E - F__ ( )	__E - F__ ( )	__E - F__ ( )

Judge's Name:________________

Date:____/____/____

Professional ( ) Nonprofessional ( )




Slim Lights
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REFRESHING LOW TAR
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